



# Results from the Tevatron (H)

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Miami 2012

Outline:

Precision EWK Measurements

Top production

QCD studies

B Physics Legacy

1985-2011

pbar-p

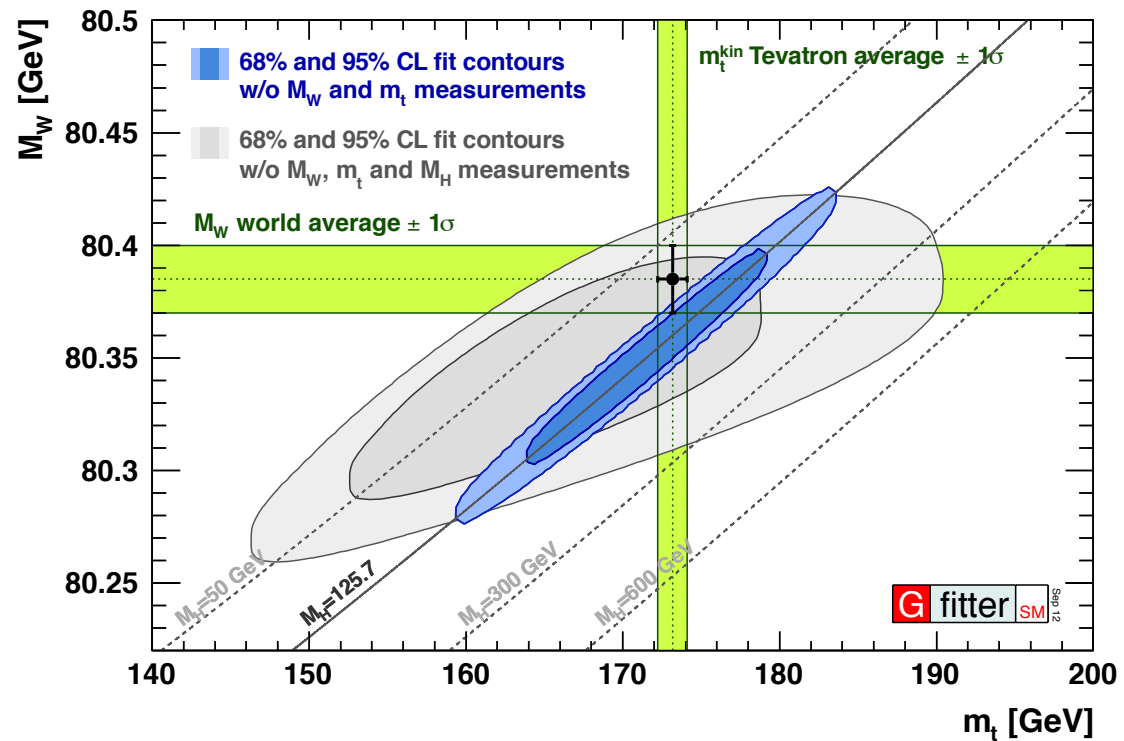
$10 \text{ fb}^{-1}$  1.96 TeV

# Precision Measurements at a Hadron Collider



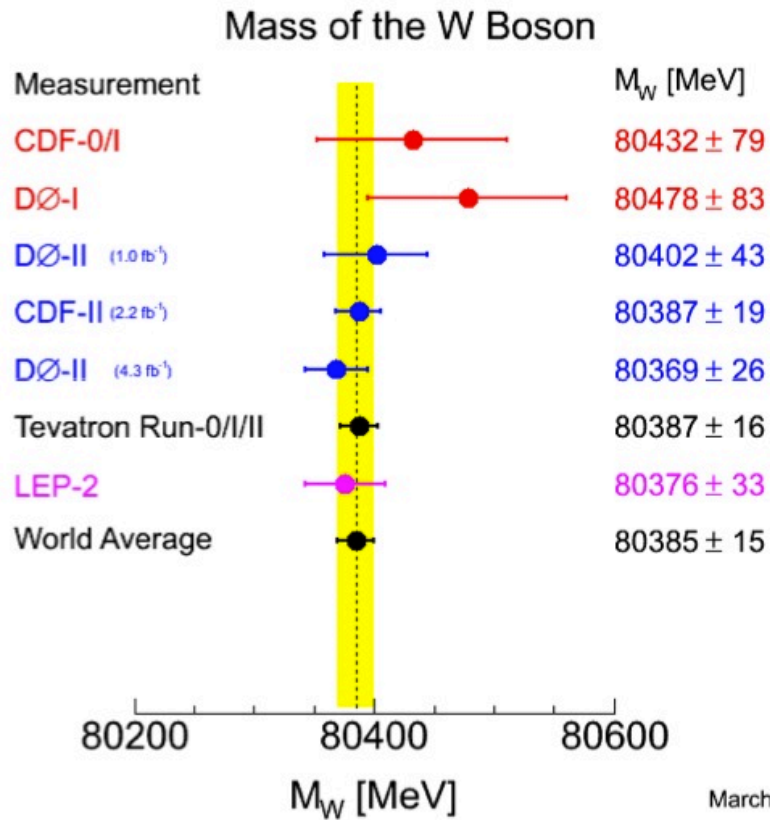
Who would have thought that when the Higgs was found the constraints on where it should be would come mainly from the Tevatron!

We also measure masses and lifetimes and mixing with a fair bit of precision





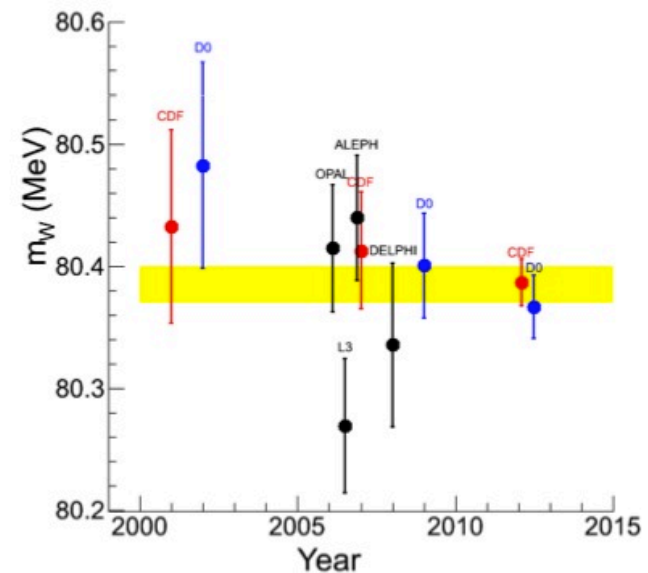
# The W Boson Mass Measurement



March 2012

Started with  $80.0 \pm 3.3$  (CDF 1988)  
Not competitive w UA1, UA2 then

Tevatron progress as seen by Mark Lancaster



DØ: PRL 108 (2012) 151804 CDF: PRL 108 (2012) 151803

Miami 2012



## W mass: room for improvement?



x4/x2 data available for CDF/D0

Technical tour de force

Precise scale from Z and whatever else you have ✓

Empirical recoil scale from Z events ✓

Fast simulation to study subtle systematics ✓

Need to understand what is in and what is out ✓  
(of lepton energy)

**World average now  $\pm 15$  MeV**

So far the new precise measurements were  
announced in PRL, not really published ☹

Prediction (meaning) of W mass is at  $\pm 5$  MeV

Current theory measurement systematics:

**$\pm 10$  MeV PDF**,  $\pm 4$  MeV QED (yay HORACE)

Use forward electrons (D0 strategy)?

Constraints on PDFs from LHC data?

**Critical mass of effort on Tevatron data??**

Very daunting at LHC!

Effect	D0	CDF
Lepton	17	7
Recoil	5	6
Background	2	3
<b>PDF</b>	<b>11</b>	<b>10</b>
<b>QED</b>	<b>7</b>	<b>4</b>
$p_T(W)$	2	5
Statistics	13	12
Total	26	19



# The Top Quark Mass (GeV)



Many generations of measurements in all modes

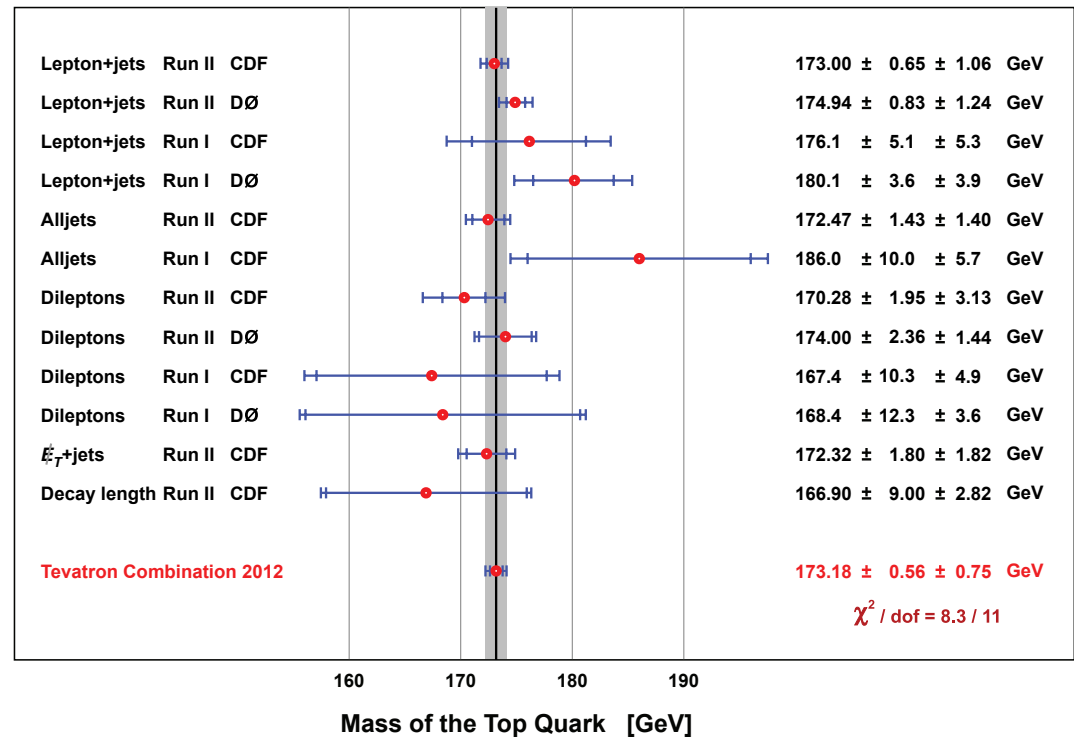
$174 \pm 10 \pm 13 \pm 12$  (1994 CDF)

$173.2 \pm 0.6 \pm 0.8$  now  
(Tev comb.)

Channels agree

LHC:

statistics better, systematics coming along,  
value agrees, how dull, already passed us by in +/- ratio ...



# Top Mass Systematics



$\Delta m(t) \sim 1 \text{ GeV} !?!$   
Can you do that?

Overall systematic of  $\sim \pm 0.6$   
from “signal modeling” –  
perhaps contains “just what are  
we measuring, anyway” of  
 $> \Lambda_{\text{QCD}}$  or  $m(\pi)$

CDF II Preliminary  $8.7 \text{ fb}^{-1}$

Systematic	$\Delta M_{\text{top}} \text{ (GeV}/c^2\text{)}$
Residual JES	0.4
Generator	0.4
PDFs	0.2
b jet energy	0.2
Background	0.2
gg fraction	0.3
Radiation	0.3
Trigger simulation	0.1
Multiple Hadron Interaction	0.2
Color Reconnection	0.3
Calibration	0.2
Total Effect	0.9

Combination:  
Phys. Rev. D 86, 092003 (2012)

Sample systematics table from the  
template CDF lepton + jets measurement

## Top Width measurement too



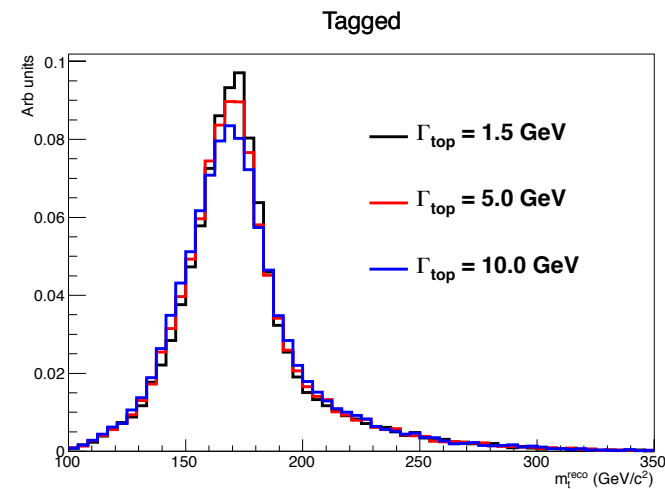
CDF: direct (preliminary)  
Fix mass, float width in  $m_{\text{reco}}$  fit

$$\Gamma(\text{top}) = 2.21 +1.81 -1.11 \text{ GeV}$$

D0: indirect  
 $\Gamma(t \rightarrow Wb)$  t channel single top  
BR( $t \rightarrow WB$ ) from top pairs

$$\Gamma(\text{top}) = 2.00 +0.47 -0.43 \text{ GeV}$$

PRD **85** (2012) 091104R



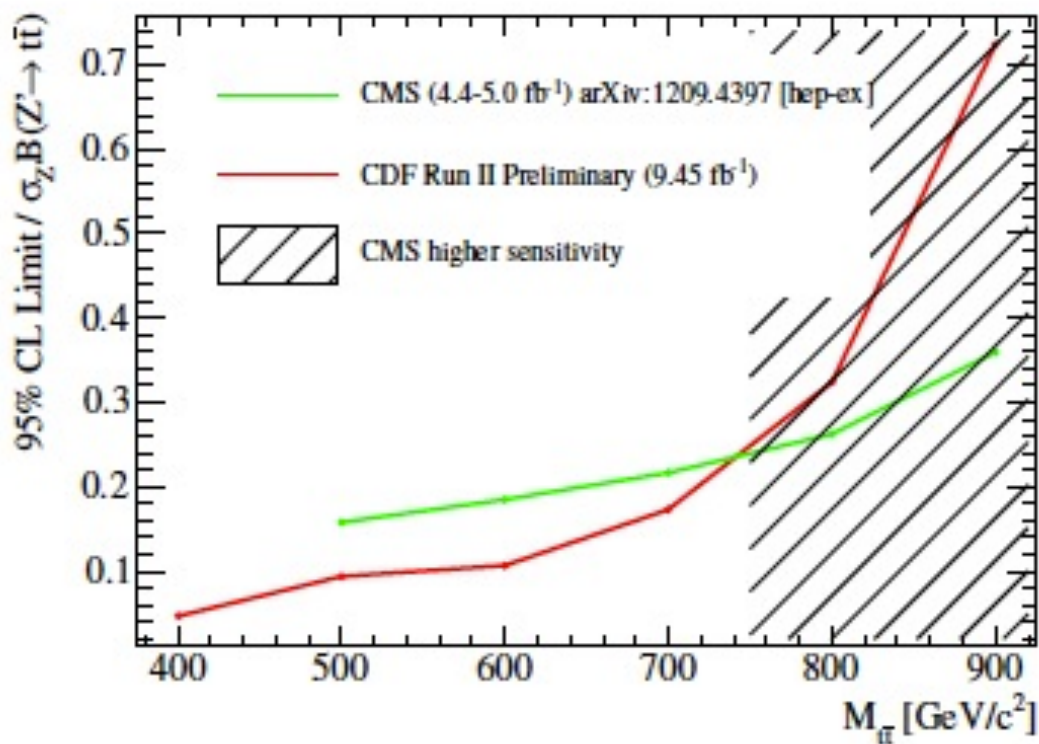
Width variation templates

**Yes indeed, top is a quark but  
not a constituent!**

## Top pairs as a place to do bump hunting



The top quark is the heaviest particle so far, perhaps it is connected to new stuff. Lots of models (eg.  $Z'$ ) of new physics predict resonances which decay to top pairs. We no longer hold the high ground but we do cover the low end with semileptonic top pairs (CDF full sample) arxiv:1211.5363





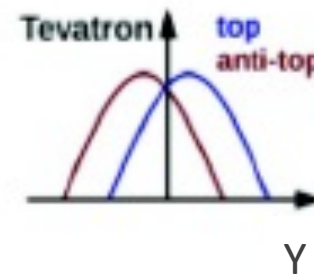
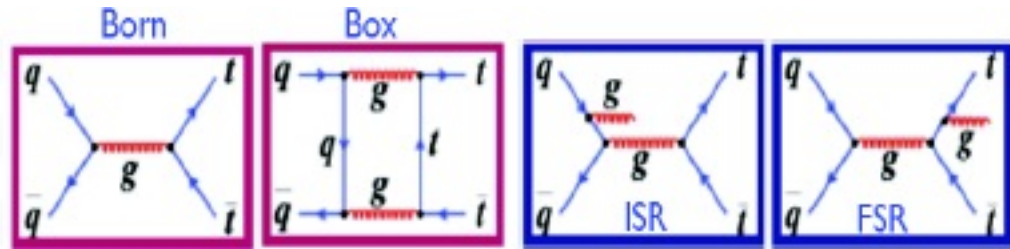
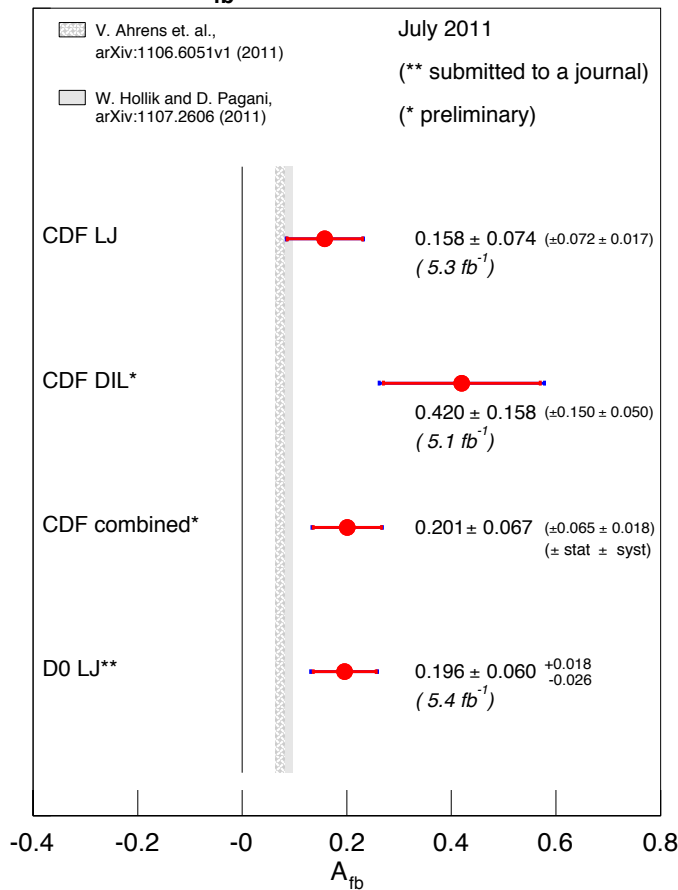
# Fun with Top in proton antiproton collisions

$A_{FB}$



Naïve expectation: annihilation or gluon production are symmetric, Z's could make interest!  
Look, find, but wait interference at NLO (with EWK enhancement), should be asymmetric!

$A_{fb}$  of the Top Quark



Cross section fine,  $A_{FB}$  too high, variation with kinematics seems as predicted but scaled up

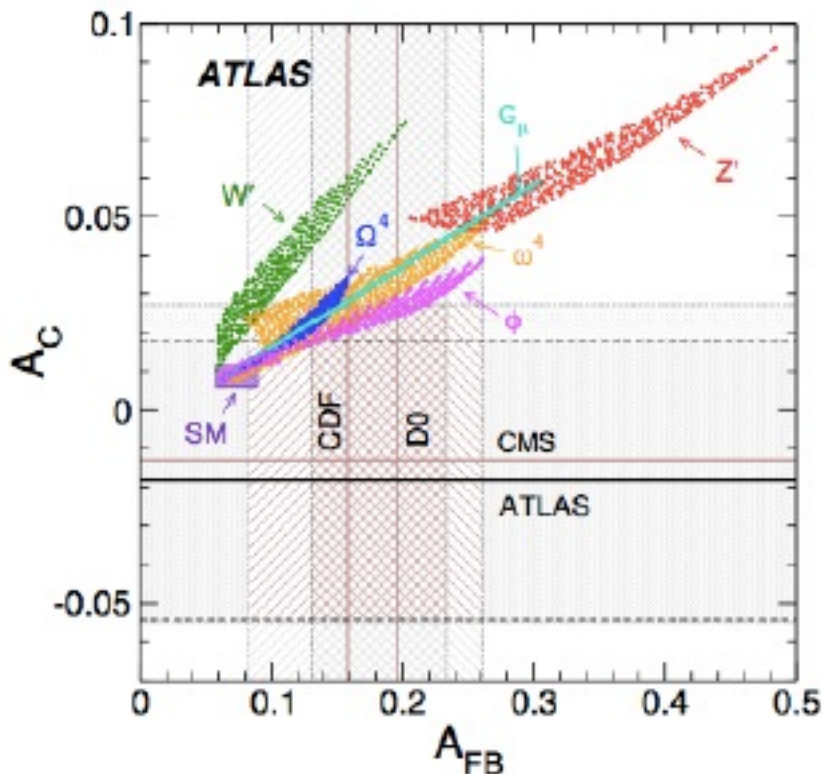
LHC  $A_C$  is different,  $qg$  initial state makes forward top



## Top $A_{FB}$ : “A Fine Mystery”<sup>+</sup>

<sup>+</sup> R. Demina, HCP

Some new physics interpretations are possible



But perhaps “SM” needs more work – it is “leading order in the effect” and electroweak corrections enhance this much a lot (~30%). An excellent field for demonstrating higher order QCD (&EWK) tools! Unlike Tev, at LHC the measurements will also improve!

Brodsky arxiv:1205.1232 thinks scale setting makes it go away but Mangano\* at HCP was not buying

\* Thanks for all the stuff I stole

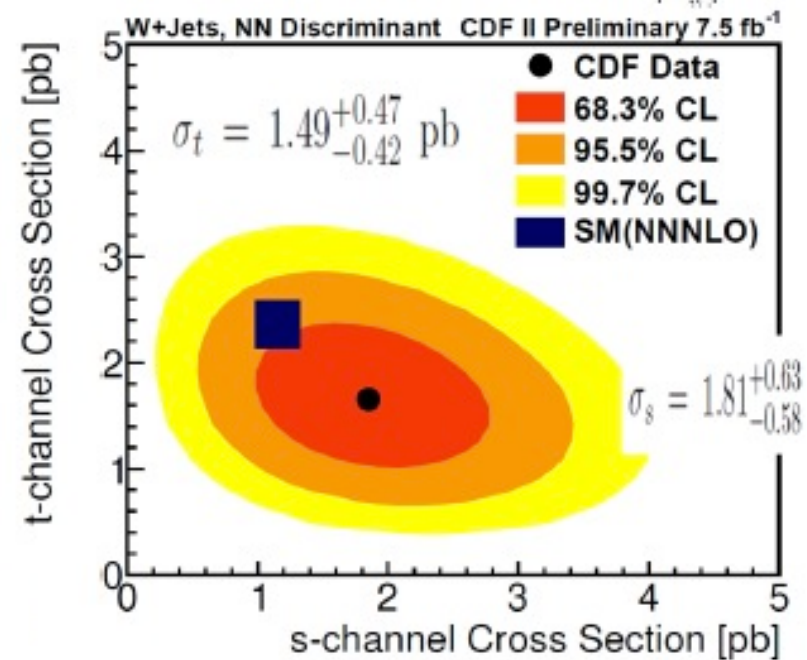
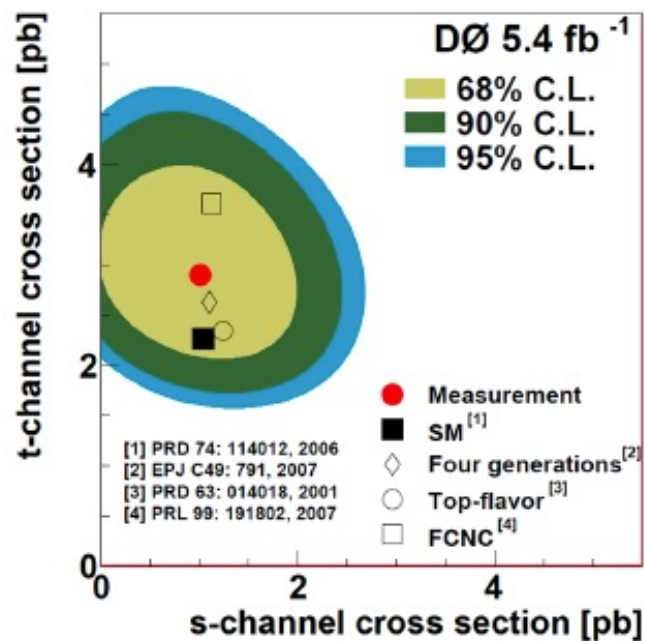
## Single Top at the Tevatron



Tiny cross sections, MVA demonstration project

Can do s & t channel unlike LHC does t and Wt (and may eventually do s)

Can derive limits on couplings SM does fine



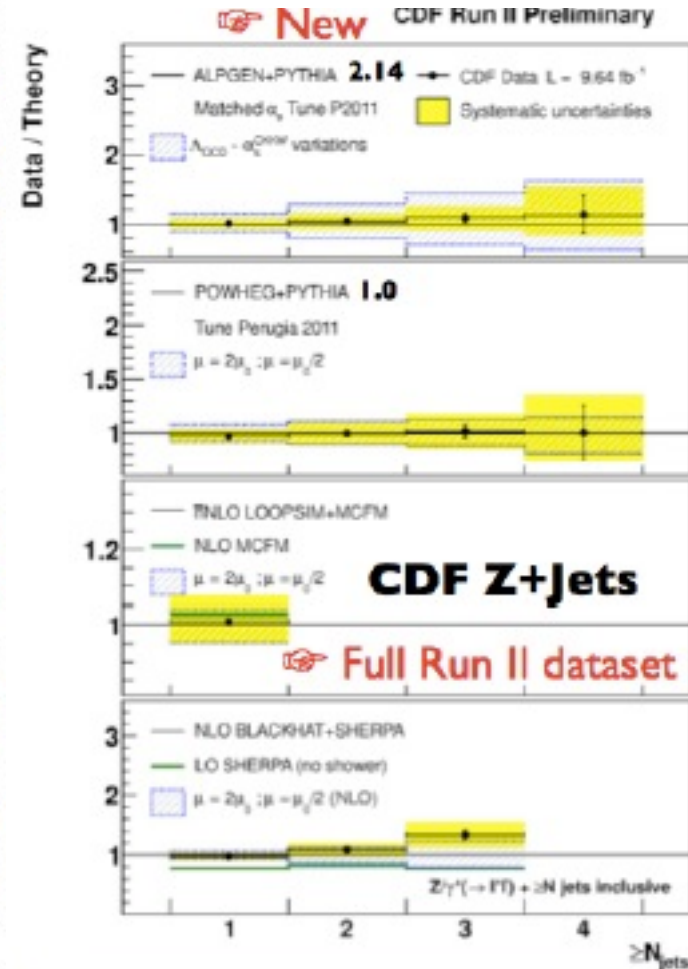
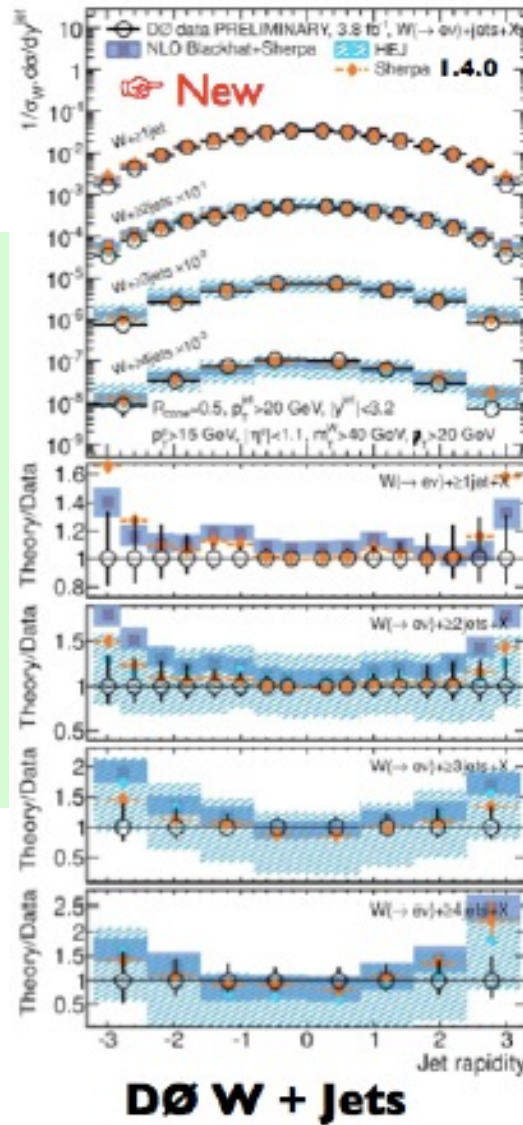
# Testing the new QCD tools with V+jets



Lose a mystery!?

**Wb** NEW DØ  
arxiv:1210.0627  
≤ MCFM, MadGraph  
Unlike  
CDF PRL 104 131801  
(was x2 high)

ALPGEN, POWHEG,  
LOOPSIM, BLACKHAT etc.

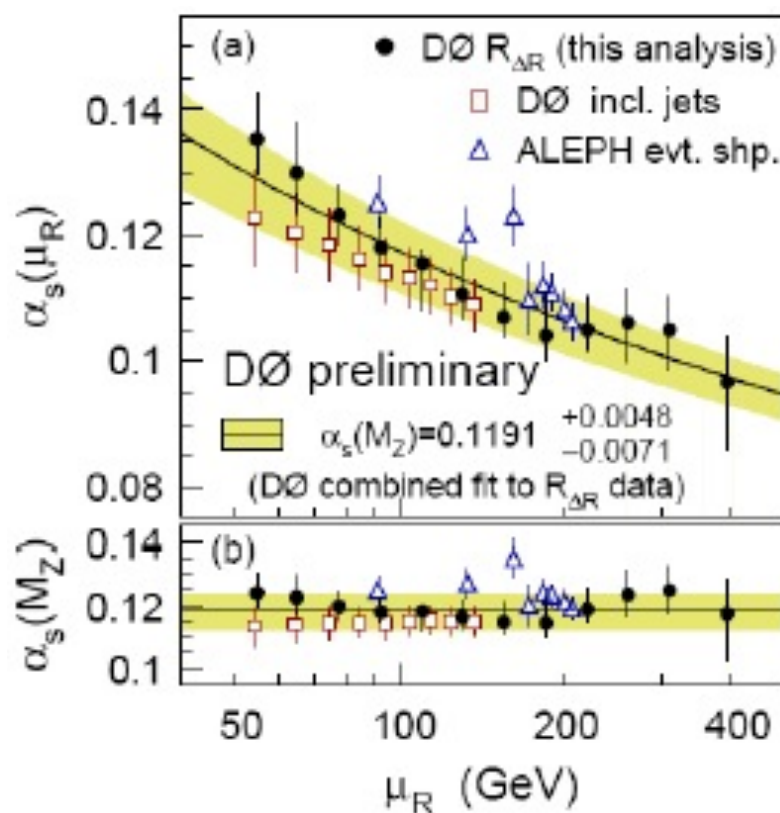




## RGE Free Running $\alpha_s$ beyond LEP



Jet distributions depend on RGEs built in to PDFs, somewhat impure for demonstrating the running coupling – DØ uses multijet event shape ala LEP!

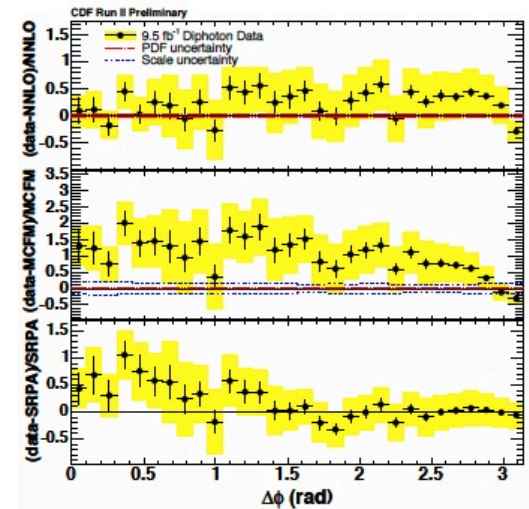
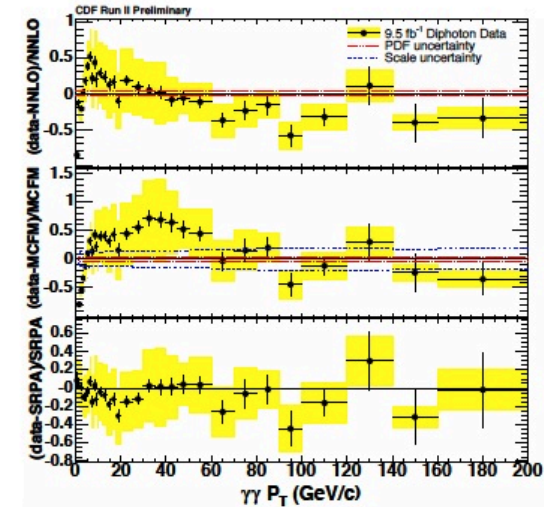
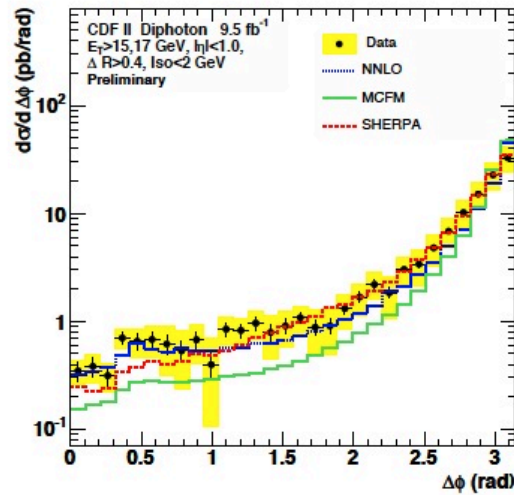
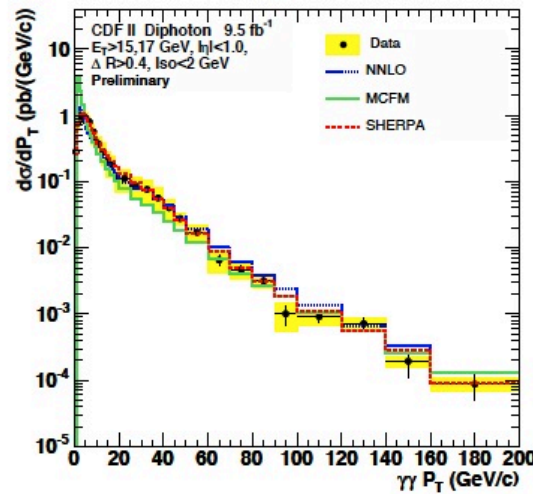


Confirms RGE predictions extending from LEP (208) to 400 GeV

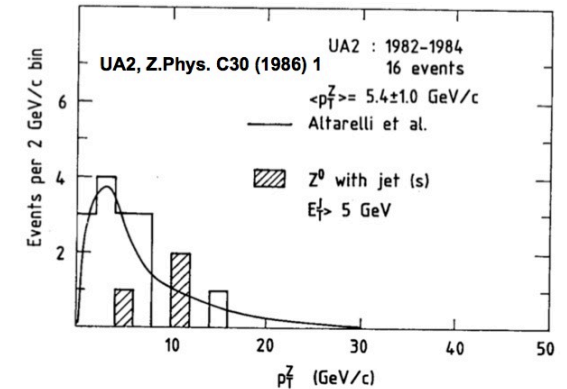
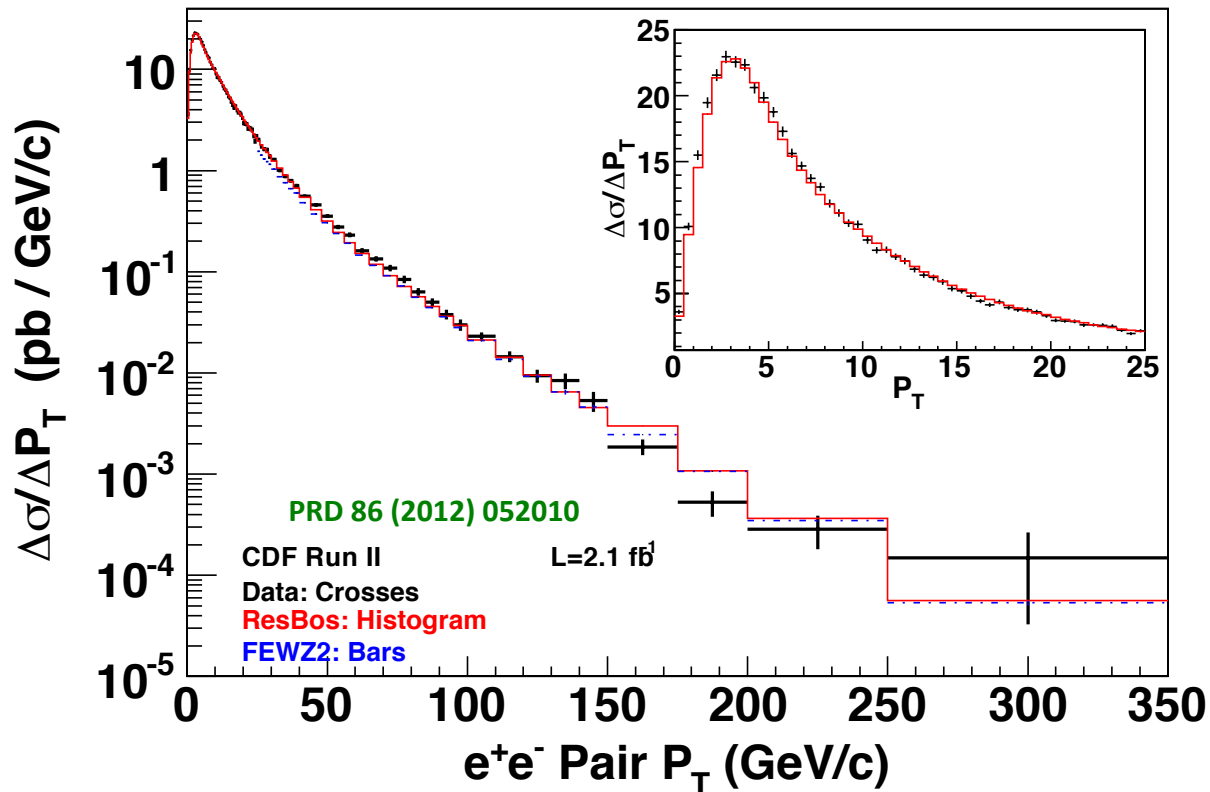
# Isolated $\gamma\gamma$ a test of new QCD tools



Note that SHERPA and NNLO calculations get the fragmentation bump in the  $p_T$  spectrum due to fragmentation and NNLO even describes the narrow angle region



## Tuning tools: Z $p_T$

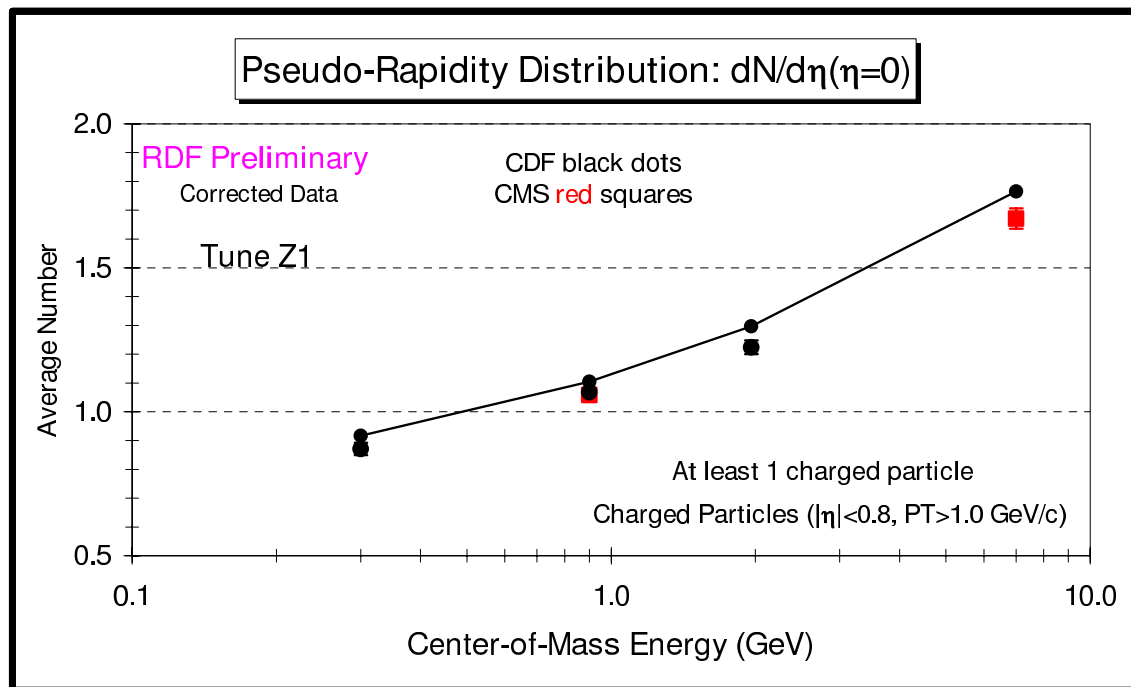


We've come a long way!

Apparently the D0  
novel technique of  
PRL 106 (2011)  
012007 has not gone  
viral

High  $p_T$  is the new usual suspects, low  $p_T$  is resummation (RESBOS)

## Tuning Semi-empirical Tools

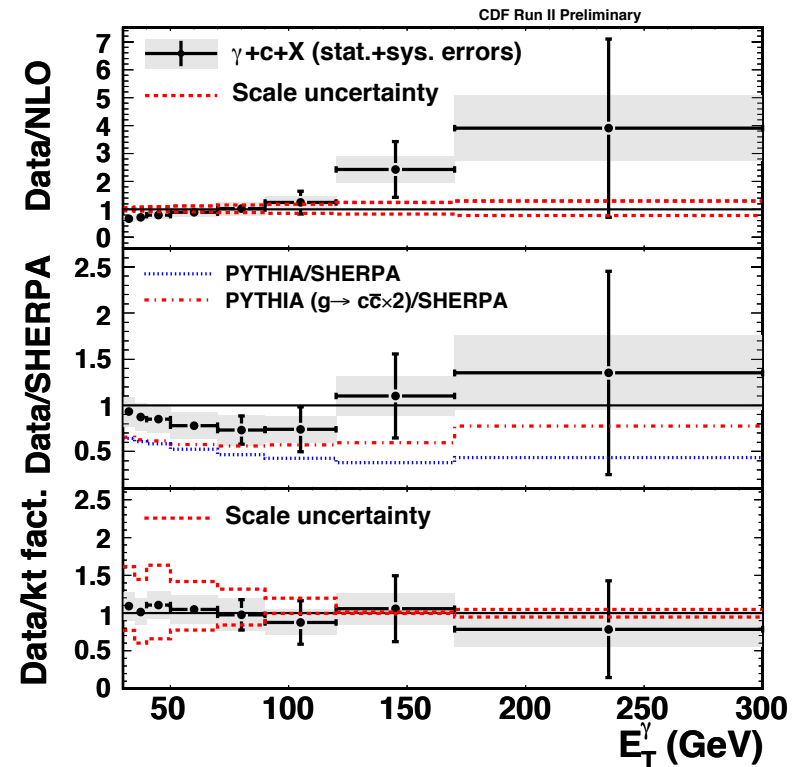
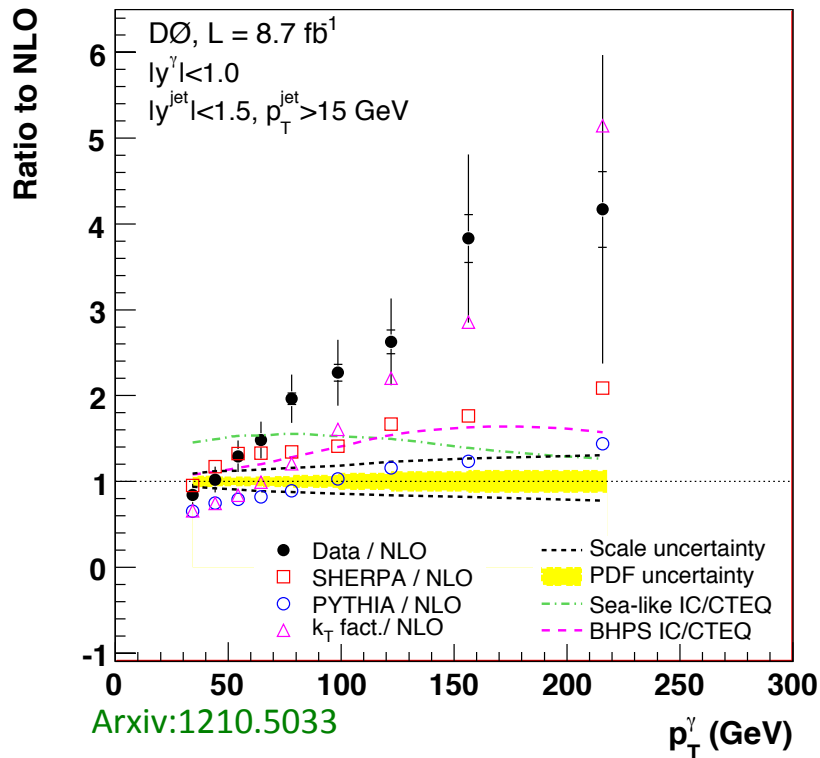


RDF = Rick Field = both CMS and CDF

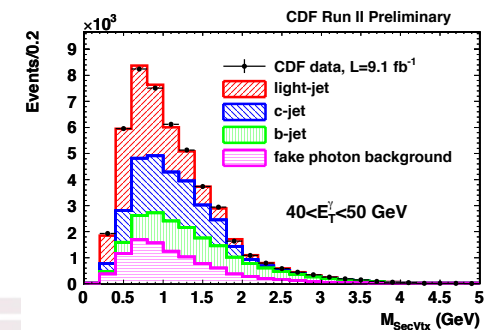
Rick Field & co. are engaged in a comprehensive program using CDF scan data taken shortly before shutdown as well as CMS data to try to understand and simulate underlying event and minimum bias physics



# $\gamma$ + charm

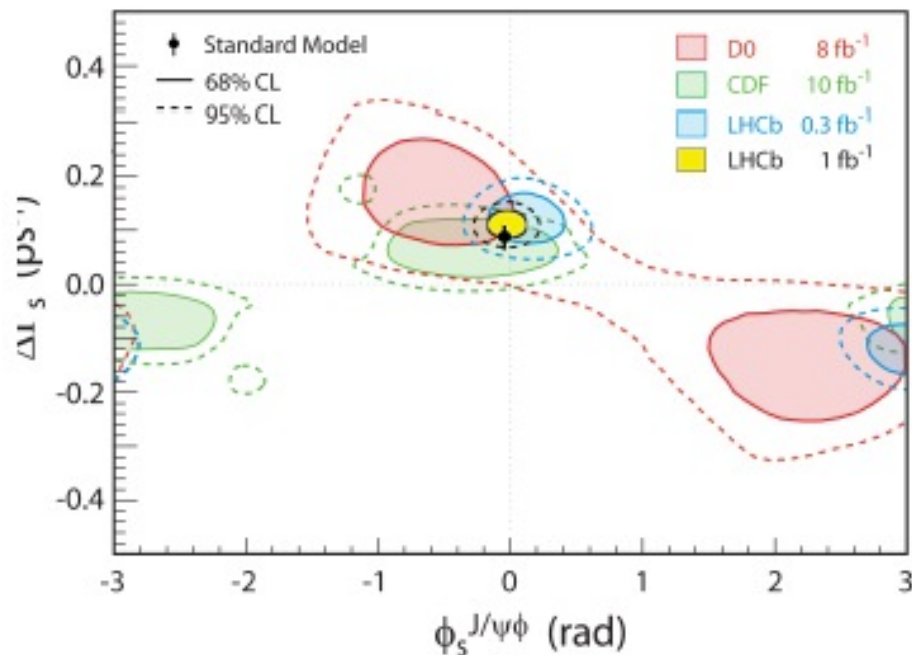


Fit vertex mass for flavor composition, unlike  $W+b$ , here CDF looks more as expected: attempting to resolve! Need to enhance gsplrit?

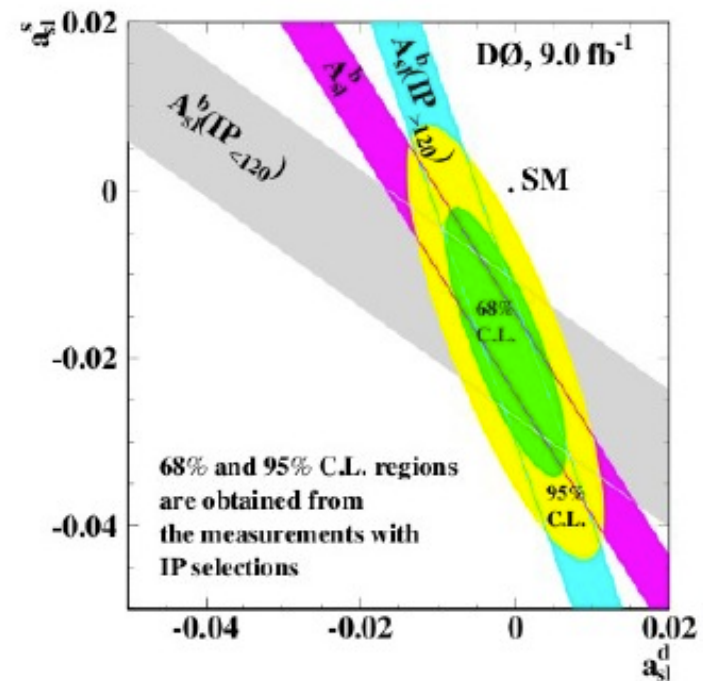


## Legacy in B Physics: Precedents

There are a lot – these are examples:



This was much more interesting back when both CDF & D0 were off left



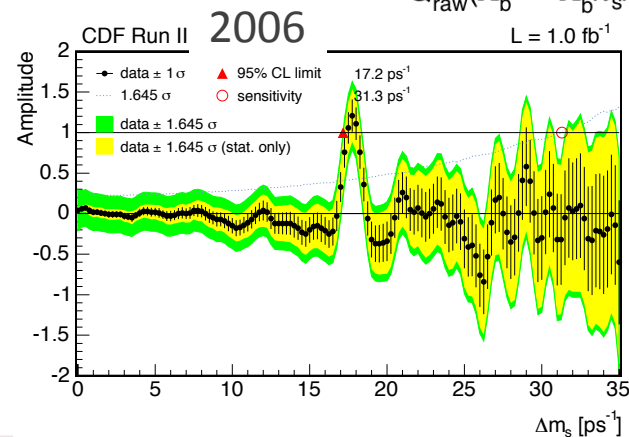
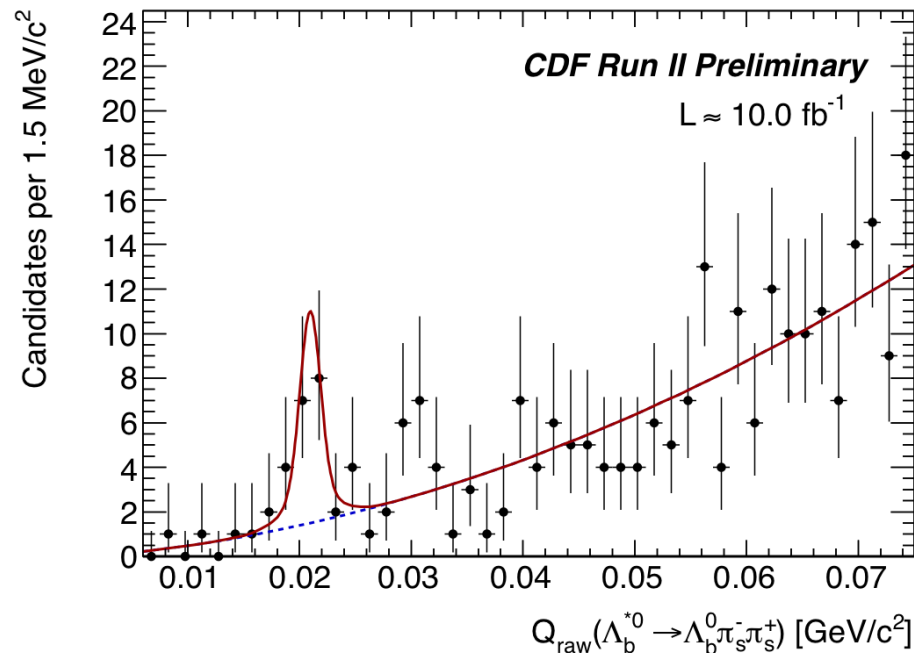
3.9  $\sigma$  muon asymmetry reduced broken down d & s, add LHCb etc  $A_d/A_s \rightarrow 2.9 \sigma$  (hmmm)

## Legacy B Physics: Lots of PDG entries!



Many new particle entries: an example  
the  $\Lambda_b^{*0}$   
 $m = 5919.5 \pm 0.4 \pm 1.7$  MeV  
(confirming LHCb)

**A highlight of the Tevatron  
Run II program is  $B_s$  mixing  
Nice of LHCb to confirm!  
The program continues**



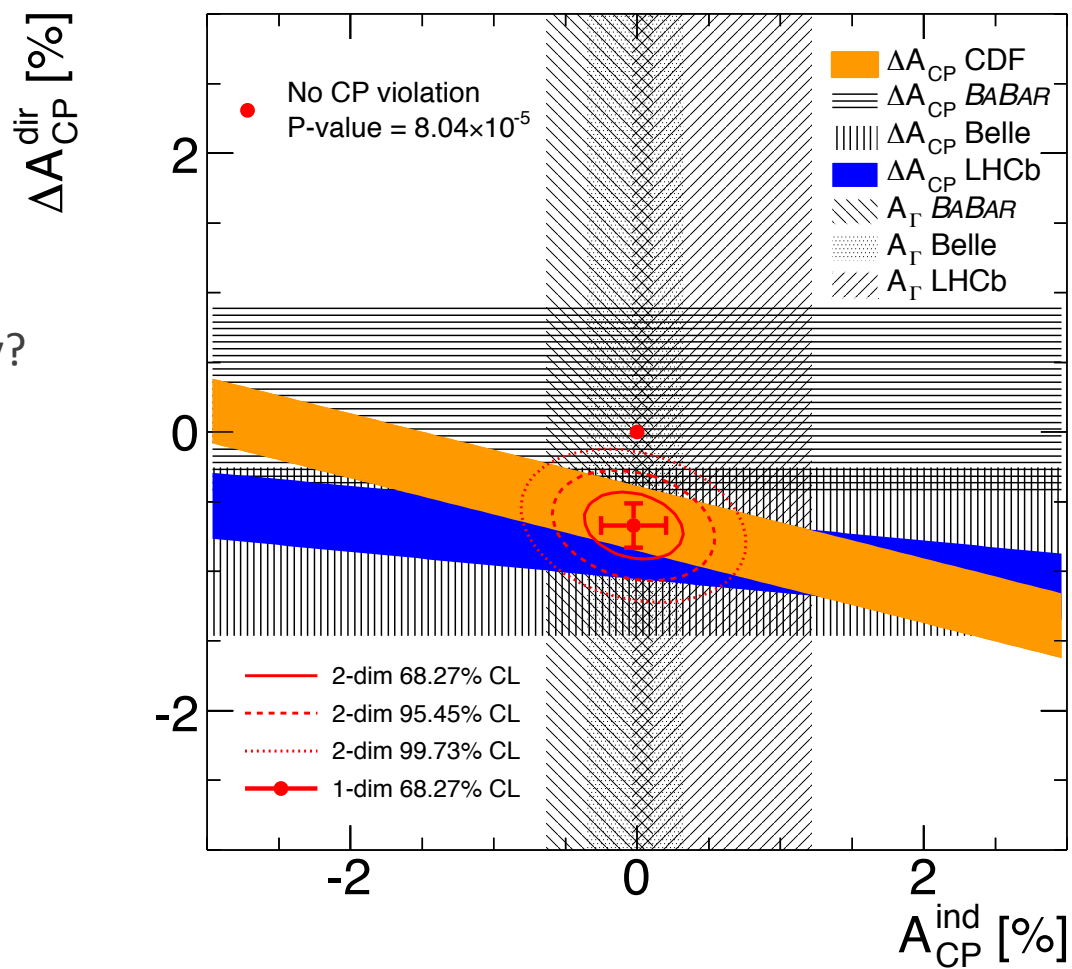
## Some HF results are quite topical!



CP violation in D decay?

Not supposed to!

Well “hardly ever?”





## Some concluding thoughts



The baton for not finding SUSY (etc.) has been passed

The Tevatron experiments have gone beyond any expectations in making precise measurements providing important EWK constraints – Yes perhaps that thing at 125 GeV is the SM Higgs

The top quark has been central to the Tevatron program and some of our measurements are of continuing interest, others are better at LHC -  $\delta m(t) < 1$  GeV

Our QCD data is a good testbed for the improving pQCD calculation tools

Lots of B (&D) physics measurements, precedents (eg. Si tracking and triggering), PDG entries, challenges for LHCb and the heavy flavor community, Lattice QCD helps

Still some good physics to do with  $10 \text{ fb}^{-1}$  @ 2 TeV charge symmetric collisions but will need critical mass

For more see <http://www-d0.fnal.gov/results/index.html>  
and <http://www-cdf.fnal.gov/physics/physics.html>

Thank you!